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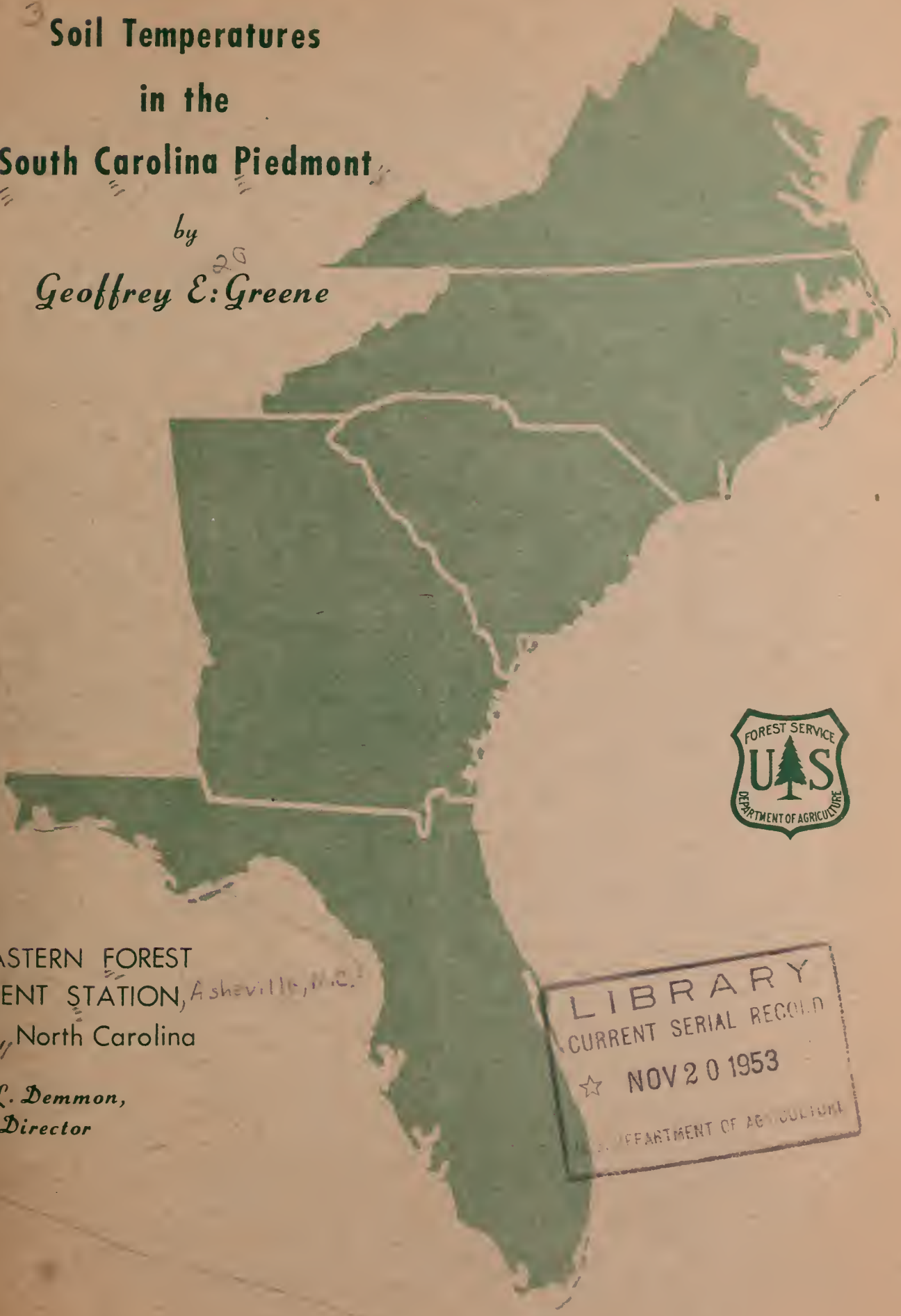
by

Geoffrey E. Greene



SOUTHEASTERN FOREST EXPERIMENT STATION,
Asheville, North Carolina

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SOIL TEMPERATURES IN THE SOUTH CAROLINA PIEDMONT

by

Geoffrey E. Greene

INTRODUCTION

This paper reports temperatures in the upper 6 feet of soil under four conditions of plant cover in the South Carolina Piedmont. Such information has not been reported previously.

The temperature of the soil is important because it is one of the limiting factors to root growth. Plant growth has been found to be accelerated within certain ranges of soil temperature and inhibited or prevented beyond such boundaries. Consequently, knowledge of soil temperature may be useful in determining suitability of planting sites, length of growing season, and periods of most rapid growth.

Temperature information was obtained from an installation of fiberglas electrodes used in the determination of soil moisture by the electrical resistance method. The fiberglas units contained thermistors for temperature measurements and were buried beneath barren, grass, and forested sites.

Observations were made at the Calhoun Experimental Forest located 7 miles southwest of Union, South Carolina. Monthly average soil temperatures were derived from daily observations taken during the period September 1950 through October 1951.

Soil temperatures have been studied extensively in Europe and in this country. Geiger (5) refers to most of the European studies in his treatise on microclimate. In this country, many of the studies of soil temperature have been made in the West in connection with frost damage to orchards (9, 8). From the engineering aspect, Crawford (4) has summarized what he believes to be the most important publications in English on the subject. For the influence of forest cover on the temperature of the soil, the reader is referred to Kittredge (7). More recently, Hursh (6) has reported temperature information for the upper 6 inches of soil under hardwood forest, grass, and barren conditions in the Copper Basin of Tennessee.

CLIMATE AND SITE DESCRIPTIONS

Climate of the South Carolina Piedmont is humid, with relatively mild winters and hot summers. In the vicinity of Union, the growing season has an average length of 208 days. The average date of the last killing frost in the spring is April 5 and the first in the fall is October 30. Mean precipitation is 47.61 inches. Rainfall distribution is fairly uniform throughout the year. An index to local meteorological conditions for the period of soil temperature measurement is given by the summary of climatological data in table 1. The data were obtained from a weather station at the experimental forest headquarters. All the soil temperature measurements were made less than 3 miles from this station. Table 1 gives mean daily maximum and minimum air temperatures by months for the period August 1950 through October 1951. Also in table 1 are monthly departures of temperature and precipitation from the 59-year average values for Santuck, South Carolina, which is 11 miles east of the study area.

Air temperatures were highest in August with a mean of 80.3°F., and were lowest in December with a mean of 38.4 degrees. It will be noticed that air temperatures during the 15-month period were generally lower than the 59-year average. Monthly precipitation was deficient in all but 3 months and there was a total deficit of 19.41 inches for the period (table 1).

The sites where soil temperatures were measured are located on nearly level ridge top or upper slope positions on soils of the Cataula and Lloyd series. These soils are derived from granites, gneisses, and schists and are characterized by red-clay B horizons 4 to 6 feet thick. Individual characteristics of the four areas reported are described below, and their locations with respect to one another are illustrated in figure 1.

Shortleaf pine-hardwood (Plot A).--The area representing older forest growth was formerly agricultural land but has not been cultivated for at least 50 years and is only moderately eroded. It faces northwest on a slope of about 8 percent. The soil is a Cataula sandy loam with horizons comparable to those at the loblolly pine plantation except that a humus layer is present. Vegetation consists of 40 to 50-year-old shortleaf pine (P. echinata, L.) with an understory of hardwoods composed principally of dogwood (Cornus florida) and hickory (Hicoria spp.). The shortleaf pines average 5.8 inches d.b.h. and heights range up to 50 feet. Most of the hardwoods are less than 2.5 inches in diameter. Of the trees 4 inches and larger in diameter, there are 520 per acre with a basal area of 141 square feet. The forest floor is from 2 to 3 inches thick. Temperature measurements were made within the stand about 100 feet from an unsurfaced road (fig. 1).

Loblolly pine plantation (Plot B).--This site is situated on the upper portion of a broad ridge that slopes about 3 percent to the southeast. It was last cultivated in 1940. The soil is a Cataula sandy loam. The topsoil has no humus layer and is about 5 to 7 inches deep. It lies

Table 1.--Mean daily maximum and minimum air temperatures by months, and total monthly precipitation at the Calhoun Experimental Forest from August 1950 through October 1951.

Year and month	Temperature				Precipitation	
	Max.	Min.	Mean	Mean departure 1/	Total	Departure 1/
	- - - - - Degrees F. - - - - -				Inches	Inches
1950						
August	89.7	63.6	76.7	-1.6	3.10	-2.69
September	81.2	58.1	69.7	-4.0	3.07	-0.37
October	77.0	51.4	64.2	2.1	3.92	0.88
November	62.2	31.7	46.9	-4.3	0.82	-1.83
December	50.0	26.9	38.4	-5.3	3.04	-1.21
1951						
January	56.0	30.2	43.1	-0.2	1.86	-1.94
February	57.8	29.7	43.8	-0.6	2.23	-2.21
March	63.3	39.6	51.5	-0.9	4.32	-0.06
April	71.9	45.1	58.5	-1.8	2.35	-1.12
May	83.9	50.1	67.0	-2.4	0.77	-2.59
June	89.7	63.4	76.5	-0.3	4.84	1.03
July	92.6	65.4	79.0	-0.4	3.65	-1.53
August	94.2	66.4	80.3	2.0	0.89	-4.90
September	85.5	60.6	73.0	-0.7	4.67	1.23
October	77.2	50.6	63.9	1.8	0.94	-2.10
Total					40.47	-19.41

1/ Difference between measurements taken at the experimental forest headquarters and the 59-year average at the U. S. Weather Bureau cooperative station at Santuck, South Carolina.

over a clay B horizon that extends to 4 feet. The C horizon begins at 4 feet and is made up of decomposed gneiss or granite. Loblolly pines were planted early in 1941. In September 1950, they averaged 5.3 inches d.b.h. and 31.1 feet high with a crown density of about 58 percent. There were 760 trees per acre with a basal area of 103 square feet. The forest floor, composed of weathered pine needles, was 2 inches deep and weighed approximately 13,000 pounds per acre.1/ Soil temperatures were measured at a point well within the stand about 130 feet from the nearest opening.

1/ Based on oven-dry weight.

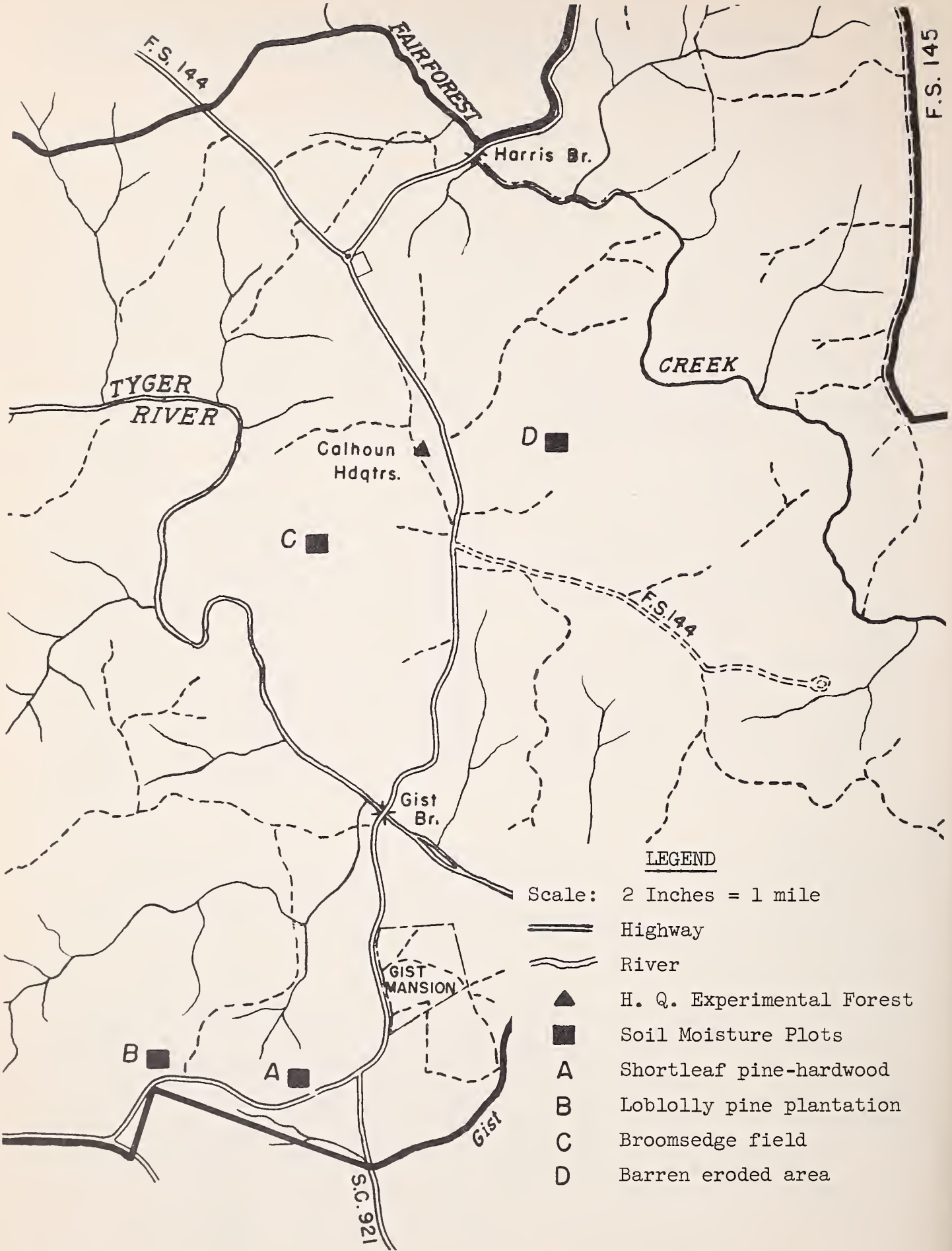

Figure 1.--Location of soil moisture plots on the Calhoun Experimental Forest, where soil temperature information was obtained.

Broomsedge field (Plot C).--This site is an old field situated on a ridge top that slopes about 3 percent southward. It was last cultivated in 1942. The soil is a Lloyd loam. Topsoil is present in the form of a brown loam about 6 inches deep. The subsoil is a stiff clay that extends from 6 to 72 inches. It is less compact and more permeable than are soils of the Cataula series. Vegetation is predominately broomsedge with a cover density of 95 to 100 percent. It has been maintained in that cover type by periodic removal of invading pines.

Barren site (Plot D).--This area is a relatively level portion of an old field situated on a ridge top that rises steeply on the north side. It was last cultivated in 1930. The soil has been severely eroded and the original sandy loam surface-horizon of the Cataula series has been completely removed. The upper 28 inches of this type of clay has an angular blocky structure. Below 28 inches, mica particles and quartz fragments are abundant, and the soil has a platy structure. The fiberglas elements were installed in a fully exposed barren portion of the area. At a distance of 6 feet there are scattered clumps of broomsedge (Andropogon spp.), and at a distance of 40-feet there is abundant loblolly pine (P. taeda, L.) regeneration.

METHODS

Fiberglas electrodes (3) were installed within 25 by 25-foot fenced enclosures at each site. The electrodes were inserted at depths of 2, 12, 18, 24, 36, 48, 60, and 72 inches along the side of a 5-inch auger hole. The excavated soil was repacked into the hole to duplicate thickness and arrangement of the original soil horizons. The thermistor[2/] in each electrode was used to measure temperature. The Colman (3) ohmmeter was used to measure thermistor resistance. The resistance readings were converted to temperature in degrees Fahrenheit from graphs compiled by Colman. Thermistors of the type contained in the fiberglas units are capable of registering small temperature changes. However, with the ohmmeter used, temperature determinations are believed to be accurate to only $\pm$ 1°F. Measurements were made daily between 8:00 and 9:00 a.m. Because of the distance between plots (fig. 1), there was a time interval of approximately 40 minutes between the first observation at Plot D and the last at Plot B. This time interval was consistent from day to day and probably had no influence on comparisons of temperature between vegetated sites. It probably did affect comparisons between the barren and vegetated sites, since the barren area was read earlier in the morning before surface temperatures were materially influenced by bright sunlight.

RESULTS

The presence of vegetation had its greatest effect on soil temperatures in summer, and temperatures were progressively cooler from barren to high forest conditions. Monthly average temperatures from September 1950 through October 1951 are given in table 2 for the upper 6 feet of soil

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2/ Western Electric No. 7A.

under the four cover conditions. Annual minimum soil temperatures occurred from one to two months later than minimum air temperatures (table 1). Under forest vegetation for example, the entire 6 feet of soil was coldest in February (table 2A and B). At the grass and barren areas the temperatures in the upper 18 inches of soil reached a minimum in January and in the remainder of the 6-foot profile they were lowest in February (table 2C and D). For barren conditions, January temperatures averaged 40° at 2 inches depth and 43° at one foot. At comparable depths under vegetation the soil was warmer by approximately 3° and 1° respectively. In the zone from 2 to 6 feet the February temperature of the barren soil varied from 47° to 52°, which was generally 1° to 3° warmer than under grass or forest cover.

Except for the 2-inch depth at the barren area, the temperatures in the upper 4 feet of soil at all sites were generally highest in August, which was the time of the annual maximum air temperature. On the forested sites, the soil reached its maximum temperature at 5 feet during September and 6 feet in October, 1951. The soil at the barren site and broomsedge field reached its maximum at 5 and 6 feet in September. In table 2 it will be noted that the annual maximums at 6 feet may not occur at the same time each year. For 1950, they did not occur at any of the sites in October. At a depth of 18 inches, the soil temperatures in August averaged approximately 82° at the barren site, 77° at the broomsedge field, 74° at the loblolly pine plantation, and 71° at the pine-hardwood stand. Even at a depth of 6 feet there was an appreciable influence of vegetation on soil temperatures. In September 1951, for example, the temperature at a depth of 6 feet was 75° at the barren area and 67° under the older forest.

Table 2D shows that the 2-inch depth at the barren area reached an annual maximum in July rather than August. Because of greater day lengths and more intense solar radiation in July, the absence of shading vegetation would have the most noticeable effect on soil temperatures. Consequently, it was believed that the soil at 2 inches depth at the barren area tended to heat more before the time of observation than it did at the vegetated sites.

Although the annual extremes occurred at a later date with increasing depth, the differences between successive months were relatively small. Therefore, for most purposes of comparison, the temperatures throughout the upper 6 feet of soil can be considered to have reached a minimum in February and a maximum in August. Average temperatures by depth at three sites for February and four sites for August are plotted in figure 2. Mean air temperatures for the two months are indicated by vertical lines. Since there was no appreciable difference in the annual minimums between the two forested areas, only temperatures for the pine-hardwood stand are plotted for February in figure 2. Compared to mean air temperature for February, the soil averaged approximately 3° colder near the surface but at a depth of 6 feet it was from 6° to 9° warmer. Temperature profiles of the soils for August illustrate the influence of vegetation on soil temperatures in summer. It will be noted that the soil temperature differences between the loblolly pine plantation and the broomsedge field were appreciable down to a depth of about 3 feet. Below that depth however, the temperature differences under young forest and grass were relatively small. In August, the soil at a depth of 6 feet under vegetation was from 12° to 14° cooler than mean air temperature, while for barren conditions it was 6° cooler than mean monthly air temperature. At a depth of 12 to 30 inches the barren soil was as much as 2° warmer

Table 2.--Monthly average soil temperatures for selected depths from September 1950 through October 1951
(In degrees F.)

	Depth (Inches)	1950 Sept.	Oct.	Nov.	Dec.	1951 Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.
	UNDER A 40 TO 50-YEAR-OLD SHORTLEAF PINE-HARDWOOD STAND														
A	2	67.9	62.5	52.8	45.8	43.0	42.6	49.4	54.5	60.2	66.7	69.9	71.3	67.7	62.7
	1/12	68.6	63.7	56.0	48.0	44.2	43.9	50.1	54.4	59.7	65.5	69.4	70.7	68.6	64.1
	18	69.0	64.5	57.7	50.0	45.6	44.9	50.7	54.6	59.6	65.1	69.4	70.6	68.8	65.0
	24	68.0	64.4	58.2	50.5	45.7	44.4	49.8	53.1	57.9	62.8	67.2	69.2	68.3	65.6
	36	67.9	65.4	60.9	53.3	48.3	46.6	50.2	53.1	57.5	61.6	66.5	68.2	68.4	66.9
	48	68.2	65.8	61.8	55.4	49.5	46.9	50.5	52.8	56.4	60.3	65.0	67.4	67.2	66.5
	60	68.1	66.2	63.2	57.7	51.8	49.4	51.3	53.1	56.2	59.6	64.0	66.2	67.0	66.7
	72	66.6	65.2	63.4	58.6	52.2	50.0	50.6	52.2	55.0	57.5	61.5	65.8	66.6	67.0
	UNDER AN 11-YEAR-OLD LOBLOLLY PINE PLANTATION														
B	2	68.9	62.5	51.2	42.9	42.6	42.1	48.7	54.7	64.0	69.6	72.8	73.3	69.3	63.4
	12	70.8	65.2	56.1	46.7	44.0	44.0	50.5	55.0	63.4	68.9	72.7	73.9	71.1	66.0
	18	71.4	65.3	58.3	48.7	45.6	44.8	50.8	54.8	62.9	68.3	72.4	73.6	71.4	66.9
	24	70.6	66.5	58.9	49.9	45.7	44.4	50.3	54.0	61.3	66.6	70.6	72.4	70.7	66.8
	36	70.6	67.2	61.3	52.7	47.8	45.6	50.5	53.3	59.8	65.1	69.2	71.6	70.2	67.7
	48	71.1	68.2	63.6	55.7	50.3	48.4	51.2	53.8	59.6	64.7	69.0	71.2	71.3	68.4
	60	68.9	67.4	63.4	56.4	50.5	48.2	50.6	52.4	57.1	61.6	66.3	68.2	68.5	68.2
	72	68.8	68.0	64.9	58.8	52.8	50.4	51.4	53.1	56.8	61.1	65.5	67.7	68.2	68.7
	UNDER A BROOMSEDGE FIELD														
C	2	70.8	63.5	49.7	43.5	42.9	43.5	52.4	59.7	70.4	75.8	77.9	78.2	72.3	63.1
	12	71.2	65.3	53.8	46.2	43.8	44.9	52.2	57.9	68.5	73.9	77.4	77.8	72.8	65.5
	18	71.9	65.9	55.8	47.6	44.8	45.4	52.2	57.8	68.0	72.9	77.1	77.4	73.4	66.6
	24	72.7	67.4	59.3	51.2	48.2	47.8	53.9	58.3	67.9	72.3	76.1	77.0	74.3	68.3
	36	70.4	66.7	60.1	52.4	48.0	47.0	51.3	54.9	63.0	67.6	71.8	73.3	72.1	67.7
	48	70.3	67.5	62.6	55.4	50.3	48.9	51.8	54.3	61.1	65.8	69.7	71.7	71.4	68.5
	60	69.9	68.1	64.3	58.2	52.2	50.6	52.2	54.4	59.9	64.7	68.4	70.0	70.8	68.9
	72	68.6	67.8	65.0	59.9	53.8	51.4	52.1	53.8	58.3	62.1	66.5	68.0	68.6	68.6
	UNDER A BARREN ERODED AREA														
D	2	70.5	60.9	43.7	40.4	40.0	41.0	49.4	57.3	69.2	75.1	78.1	77.2	71.1	57.2
	12	74.5	65.8	51.9	44.0	42.6	44.1	51.4	57.7	70.6	76.8	80.2	80.7	74.9	68.4
	18	77.0	68.4	56.6	47.4	45.8	46.6	53.5	59.1	71.6	77.5	81.3	82.0	77.6	67.8
	24	77.5	69.2	59.0	49.6	47.3	47.0	53.5	58.1	70.6	76.5	80.6	81.2	77.8	71.5
	36	76.9	70.0	62.1	52.8	48.7	47.8	52.7	56.4	67.5	73.1	78.2	78.8	77.1	72.2
	48	76.5	70.9	64.2	55.9	50.4	49.2	52.6	55.6	65.0	70.4	76.2	77.3	76.8	72.4
	60	76.4	72.1	66.7	59.3	52.9	51.2	53.4	56.3	64.1	69.4	74.7	75.9	76.8	73.6
	72	75.4	72.1	67.7	61.6	54.7	52.4	53.7	55.9	62.5	67.9	71.9	74.3	75.2	73.5

1/ Average of temperatures at 10 and 14 inches.

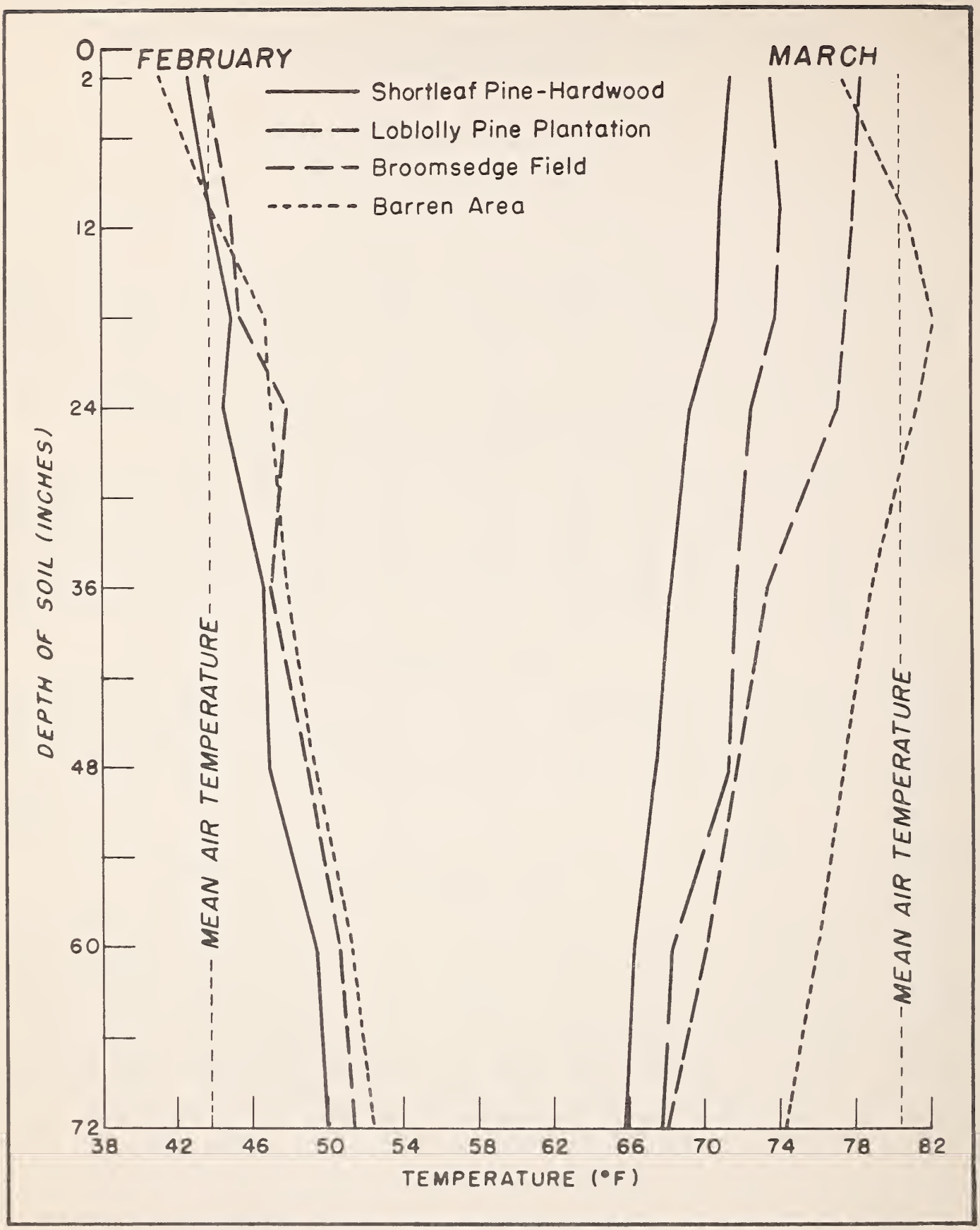

Figure 2.--Average temperature of the soil to a depth of 6 feet under a shortleaf pine-hardwood stand, a loblolly pine plantation, a broomsedge field, and a barren area, for February and August 1951. Mean air temperatures at a nearby weather station are indicated by the vertical lines.

than mean air temperature (fig. 2). In general, the temperature gradient throughout the upper 6 feet of soil at all sites tended to be linear with respect to depth, although in the upper 18 inches of barren soil there was a marked decrease in temperature with nearness to the surface. Unpublished data at this station, of hourly soil temperatures for a 24-hour period in summer, showed that the daily fluctuation was generally limited to about the upper 18 inches of soil. In addition, daily minimums in the 18-inch zone of barren areas tended to occur between 6:30 and 8:30 a.m. Consequently, the daily observations at the barren site were made when the soil was probably near its minimum temperature in the upper foot or so and would thus account for the lower temperatures upward from the 18- to 2-inch levels.

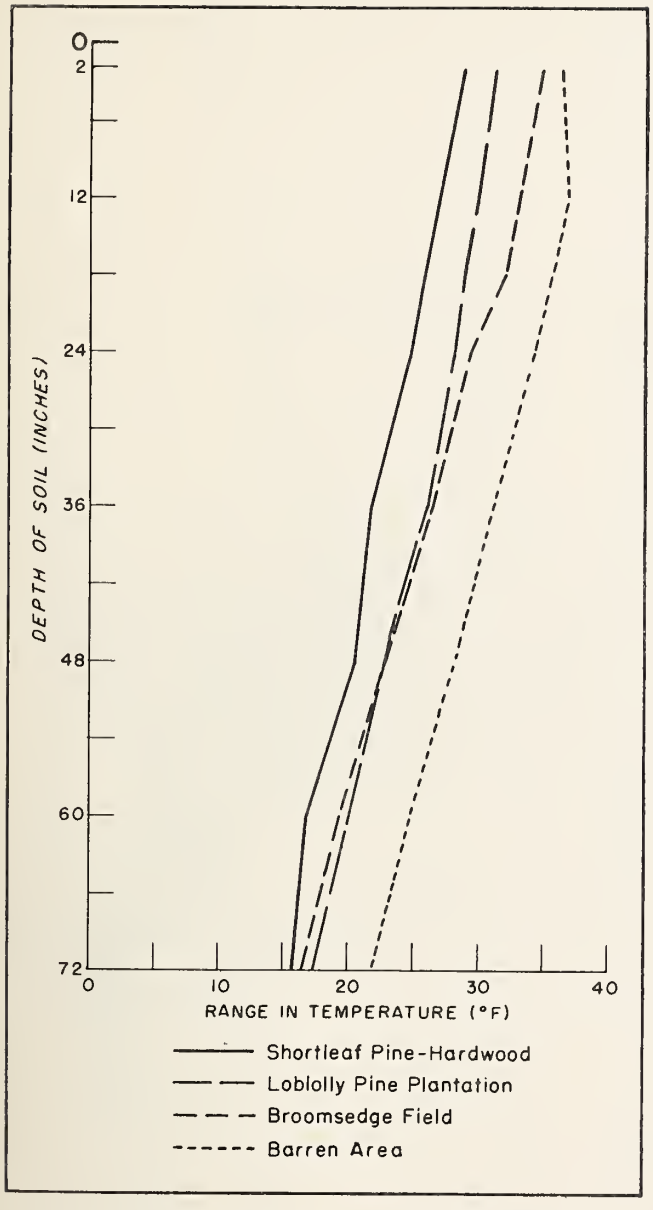

Figure 3.--Range in temperature between February and August 1951, by soil depths for each site.

A comparison of the range of average soil temperatures between February and August is illustrated in figure 3. For barren conditions, the annual range in soil temperature was 36° at 2 inches depth and 22° at a depth of 6 feet. At the same depths under the pine-hardwoods, the temperature range was approximately 29° and 16° respectively. Under young pines and grass cover the yearly range of soil temperature was intermediate between the above values.

Warming Period

The effect of vegetation on soil temperatures was noticeable throughout the year. One effect, was smaller differences in soil temperature between successive months with increasing amounts of vegetation. Seasonal changes in temperature profiles are illustrated in figures 4 and 5 for the four cover conditions. Monthly average soil temperatures were plotted by depth for two periods: one in which the soil was warming (fig. 4) and the other when the soil was cooling (fig. 5). Soil heating began in

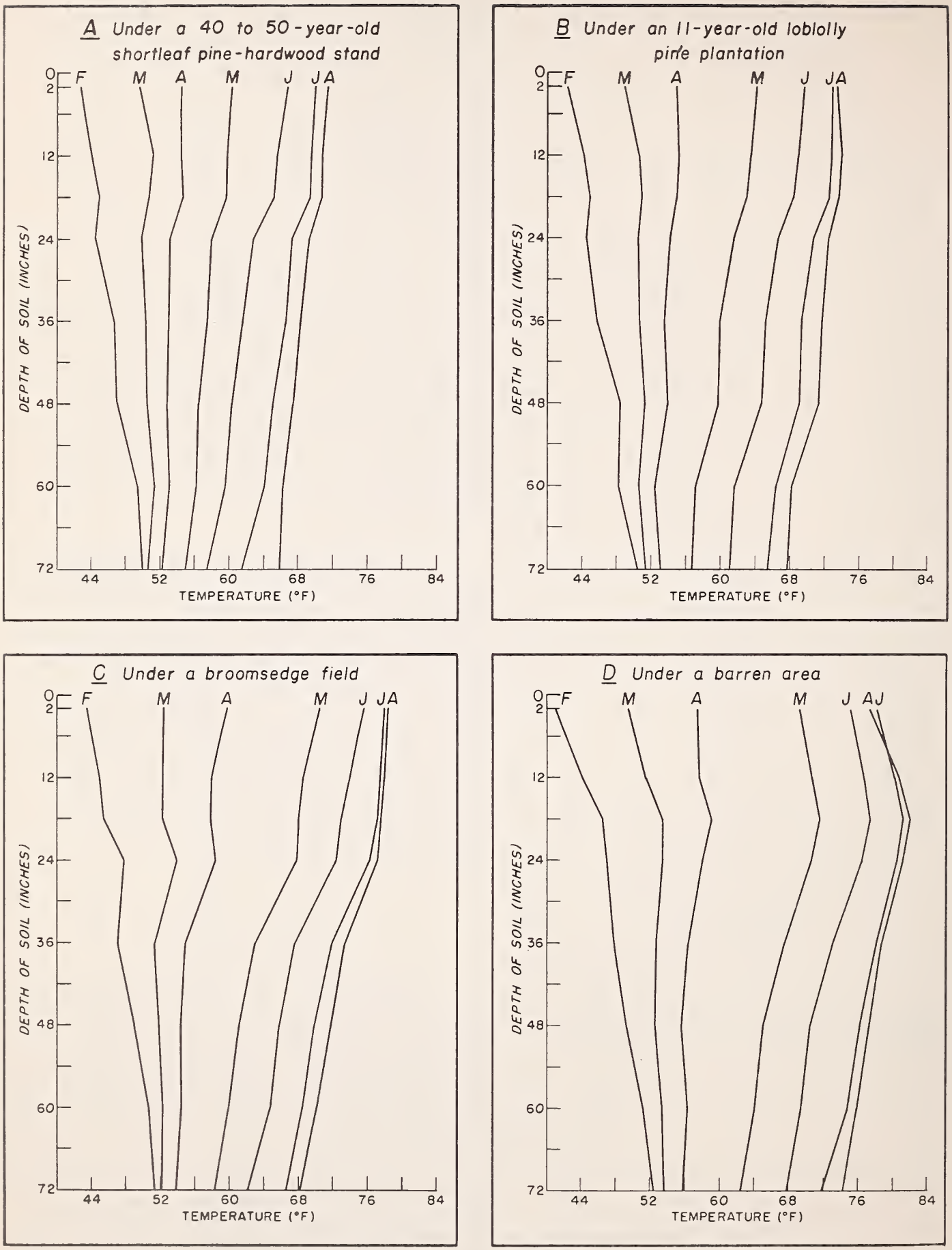

Figure 4.--Monthly average soil temperatures from February through August 1951, showing the seasonal heat gain throughout the upper 6 feet of soil.

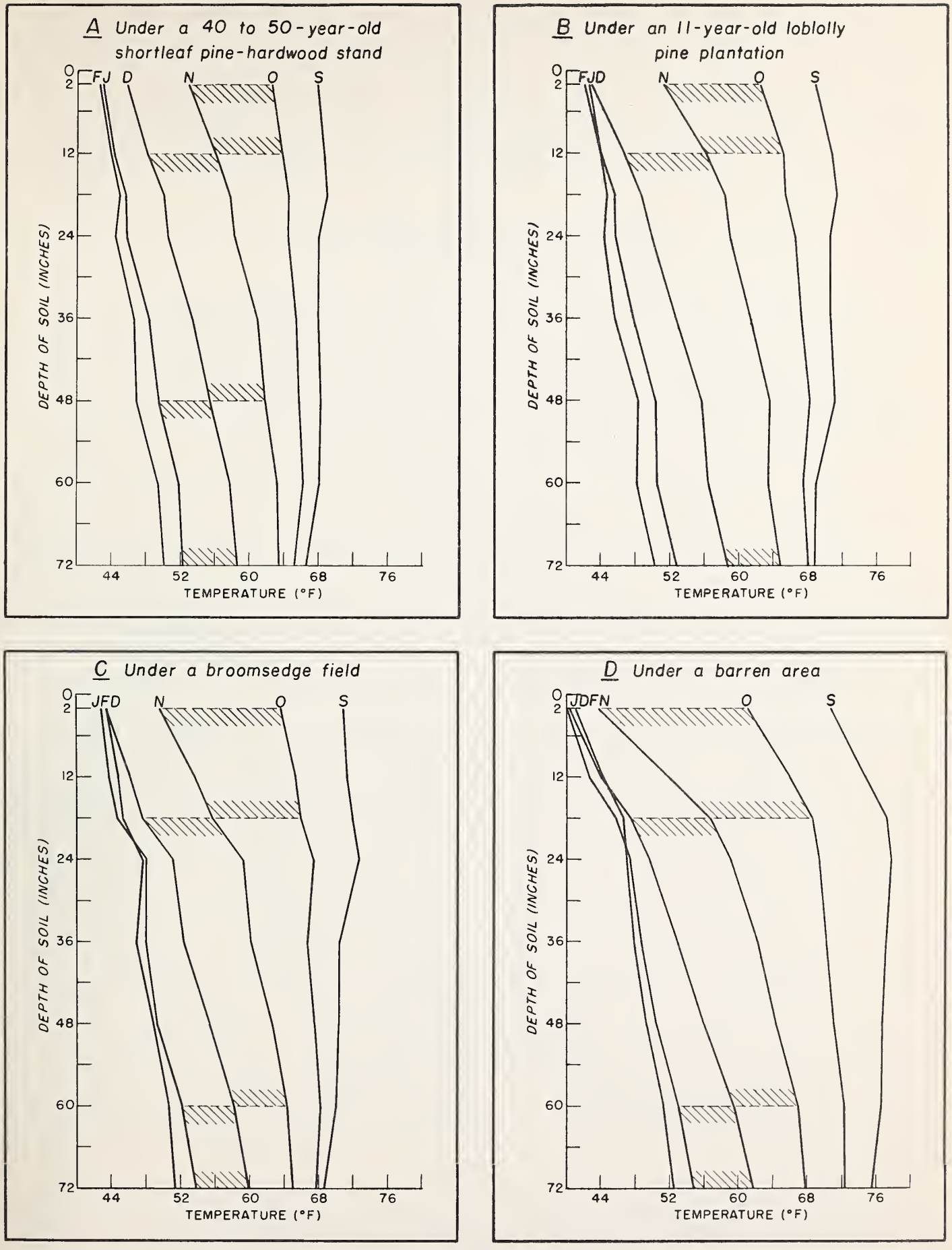

Figure 5.--Monthly average soil temperatures from September 1950 through February 1951, showing the seasonal heat loss throughout the upper 6 feet of soil. Shaded lines indicate the approximate upper and lower boundaries of depth zones undergoing the greatest heat loss for the season.

February at exposed sites, and in March at the forested areas (table 2). By the end of March, temperatures in the entire 6 feet of soil had increased from several degrees near the surface to about 1° at a depth of 6 feet (fig. 4). The period of maximum soil heating is marked by the widest divergence between successive monthly temperature profiles in figure 4. Under exposed conditions (fig. 4C and D) the upper 6 feet of soil warmed most rapidly in May as did the upper 5 feet of soil under the young pines (fig. 4B). At the barren area, for example, the upper 3 feet of soil was from 11° to 13° warmer and the 6 foot depth about 7° warmer in May than it was in April. Values for the broomsedge site were somewhat less. Under the young loblolly pines, the first 5 feet of soil was 5 to 9° warmer in May than in April, while the soil at 6 feet warmed the most in July with an increase of 4.4° over June temperatures. Under older forest cover, the upper 2 feet of soil warmed most rapidly in June, with an increase of 5 to 6° above May temperatures. An increase of about 4.5° in July marked the maximum heating from 2 to nearly 6 feet. At the 6-foot depth, the soil warmed the most in August, with an increase of 4.3° above the average temperature in July (fig. 4A).

Cooling Period

Monthly temperature profiles in figure 5 show the decrease in temperatures in the upper 6 feet of soil during the fall and winter beginning in 1950. In general, the outflow of heat from the soil began in September. By the end of October the soil had cooled to a depth of 6 feet where the decrease in temperature varied from 0.8° at the loblolly pine stand to 3.3° at the barren site. The maximum loss of soil heat in the fall and winter period extended more gradually with depth and the advance of season, in contrast to the rapid warming of the soil profiles that occurred in the spring. This lag with depth in the occurrence of maximum heat loss is indicated in figure 5 by the enclosed areas between adjacent temperature profiles, with the approximate upper and lower boundaries of given depth zones shaded to mark the largest differences in soil temperatures between successive months. In November, the maximum loss of heat reached a depth of 12 inches under forest cover and a depth of 18 inches at exposed sites. For the above zones, the decrease in soil temperatures was about 9° to 11° under forest and 10° to 17° for grass and barren areas from October to November. For the greatest portion of each soil profile, the maximum loss of heat occurred in December, with temperatures ranging from 6° to 9° lower than in November. December cooling was most rapid at the pine plantation, where the 1 to 6-foot depth cooled a maximum amount by the end of the month. Under the older forest stand, the maximum cooling of the soil in December was limited to the 1 to 4-foot zone, while the remaining 2 feet cooled most rapidly in January (fig. 5A and B). At the exposed sites, the soil from 1-1/2 to 5 feet cooled the most in December and the 6-foot depth in January (fig. 5C and D).

There were two periods, one in the spring and one in the fall, when there was very little variation of soil temperature with depth. This condition indicates that inflowing radiant heat to the upper soil layers was tending to reach equilibrium with outflowing energy from the

subsoil. For the warming period, the upper 6 feet of soil approached a constant temperature in March and April. Under the pine-hardwood stand, the least variation with depth occurred in March and was 1.9° (fig. 4A), while for barren conditions it occurred in April and was 3.5° (fig. 4D). For the cooling period, soil temperature variations with depth were least in September, with a range up to 3° for forested areas (fig. 5A and B) and 6° to 7° for exposed sites (fig. 5C and D).

DISCUSSION AND APPLICATIONS

The major differences in soil temperature among the four sites reported here are attributed essentially to the kind and amount of plant cover. The temperature of the soil depends primarily upon its ability to absorb or lose heat. Heat gains are produced directly or indirectly by radiant energy from the sun. Plant cover reduces the range of soil temperatures. Maximum temperatures are decreased by shade, and minimum temperatures are generally increased because vegetation allows less long-wave radiation from soil to sky than would occur from barren areas. Greater nocturnal radiation from the barren soil compared to the broom-sedge field was probably one reason for the lower monthly average soil temperatures at the 2-inch depth for that site (table 2C and D).

Although vegetation exerts its primary effect on soil temperatures by influencing radiation, there are indirect effects which are due to the type of plant cover. Among these is the moisture content of the soil. According to Crawford (4), a change in the amount of water present in the soil will alter all its thermal properties. Dry soil has low heat conductivity because of poor contact between the particles, with the result that temperature decreases rapidly with depth. Moisture improves the contact between particles, and conductivity increases. The specific heat, however, also increases so that the actual rise in temperature is small. For the cover conditions reported, the resistances of the fiberglas elements in August indicated that soil moisture had been depleted to the wilting point under forest vegetation but was well above that limit under grass and barren sites, at least in the 3 to 6 and 4 to 6-foot depth zones. It is quite likely that the higher moisture content of the exposed sites materially aided the inflow of heat in the summer and was largely responsible for the greater depths to which the annual maximums penetrated in August compared to the forested areas (table 2). Although the subsoil was relatively wet at the barren and broomsedge areas in August, the upper 2 or 3 feet was dry. The lower heat conductivity of this drier soil in the upper layers may have accounted for the delay in the occurrence of maximum heat loss at the exposed sites in the winter period (fig. 5). Differences in the thermal properties of sand and clay would account for some of the temperature variations among the sites at the 2-inch depth, particularly between the barren and grass areas. Sand for example, has a lower specific heat by volume than clay, and when dry, will heat more rapidly. Organic matter has a lower specific heat than either sand or clay (4). Consequently, the upper levels of the sandy topsoil layer at the broomsedge field would tend to heat more rapidly in summer and cool

faster in winter, as compared to the layer of clay near the surface at the barren area. At the forested sites the effect of organic matter in the forest floor would be obscured by the influence of the canopy overhead.

Much of the usefulness of soil temperature information lies in evaluating its effects upon root growth. Such evaluation, however, is inherently complex since the process of growth itself is complicated and the study of roots in place has many limitations. It is known, however, that plant roots elongate rapidly at favorable soil temperatures. Barney (1) found that the primary roots of 2-1/2-week-old loblolly pine seedlings grew most rapidly between 68° and 77°. Growth continued at 41° and 95° but was less than 10 percent of the maximum rate. Contrary to common opinion, it is possible that the roots of many forest trees are not necessarily dormant during the winter months but may continue to grow when the soil temperature rises above a minimum of approximately 41°. Assuming that the upper and lower temperature limits for root growth found by Barney (1) are applicable to the pine stands reported in this study, temperatures in the upper 6 feet of soil would seldom limit root growth. February for example, was the coldest month, but soil temperatures averaged 1° or more above the lower limit at the 2-inch depth. At greater depths the temperatures of the soils were increasingly favorable for root development. At a depth of 5 and 6 feet the minimum temperature at all sites ranged from 48° to 52°, which is well above the 41° minimum for root growth. On the other hand, the optimum temperatures for root elongation occurred from June to October. It is pointed out, however, that root growth in summer may frequently be curtailed by inadequate supplies of soil moisture.

Although this study was not designed to determine soil temperature effects upon root growth, the temperature information provided may be helpful in soil management on Piedmont lands. For one thing, only near the surface is the temperature of barren heavy clay soils too high for satisfactory root growth. In the upper 2 feet of the barren soil, temperatures in July and August ranged up to several degrees above the optimum for root growth. Temperatures at the surface of such land may reach extreme proportions. At a site comparable to the one reported here, maximum summer temperatures have been measured as high as 136° at a depth of 1/4 inch. For a 15-day period in July (1950) the average daily maximum at 1/4 inch was 119° (2).

But mulch of hay or pine boughs is sufficient to reduce these surface soil temperatures to a level that permits root growth. Apparently a density of living cover similar to average old field broomsedge is sufficient to prevent damaging surface-soil temperatures. Such a cover can be obtained from cool-season plants such as winter ryegrass, oats, vetch or crimson clover. These plants can be established on most barren areas by fall sowings which are limed and heavily fertilized. By making their growth during cool weather, these cover crops escape high soil temperatures and if they are allowed to stand, their dead foliage shades the soil, permitting establishment of summer growing species. Whether it is cheaper to use a mulch of dead plant material or establish a cover crop depends upon accessibility, labor costs, etc., but either system will reduce the damaging high temperatures to a safe level. Some such measure is recommended before barren sites are planted to trees.

Temperature data from this study may also aid investigations of tree root growth. The fact that subsoil temperatures do not limit root extension during winter may explain the penetration of pine roots into compact soil layers. During the winter such soil layers are moistened and may allow roots to grow into and through them, but in summer the same soils are drier and often too dense to allow penetration.

Soil temperatures also influence moisture gradients in the soil. It is intended to explore this subject in an analyses of soil moisture records.

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SUMMARY

Temperatures are reported for the upper 6 feet of soil under four site conditions in the South Carolina Piedmont from September 1950 through October 1951. The data were obtained as part of the procedure of determining soil moisture by the electrical resistance method at a barren site, a broomsedge field, an 11-year-old loblolly pine plantation, and a 40 to 50-year-old shortleaf pine-hardwood stand. Daily observations of temperature at selected depths in the profiles were averaged by months and presented in tabular and graphical form.

Presence of vegetation had the greatest effect on soil temperatures in summer, with profiles tending to be progressively cooler from barren to high forest conditions. Soil temperatures were generally lowest in February and highest in August. Soil heating to a depth of 6 feet began in March and ended in September or October. Under barren conditions the soil at a depth of 18 inches averaged about 47° in February and 82° in August, while under the pine-hardwood stand the temperatures were 45° and 71° respectively. At a depth of 6 feet, soil temperatures in February were from 50 to 52° regardless of cover conditions. In August, the temperatures at 6 feet ranged from about 66° under forest cover to 74° for barren conditions. Annual extremes of soil temperature occurred up to 2 months later than mean air temperature extremes. There was also a lag of from 1 to 2 months in the occurrence of the annual extremes with depth.

The significance of the data is discussed in the light of known effects of temperature on root growth. For conditions reported, the roots of loblolly and shortleaf pine may grow throughout the year. The high soil temperatures that preclude root growth on barren areas are apparently confined to a thin zone near the surface. Living cover similar to an average broomsedge field is believed sufficient to markedly reduce these surface soil temperatures. It is suggested that winter cover crops be planted on barren areas as a means of reducing high soil temperatures before such sites are planted to trees.

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